VOLUME VIII: CHAPTER 8

METHODS FOR ESTIMATING METHANE EMISSIONS FROM FLOODED RICE FIELDS

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DISCLAIMER

As the Environmental Protection Agency has indicated in Emission Inventory Improvement Program (EIIP) documents, the choice of methods to be used to estimate emissions depends on how the estimates will be used and the degree of accuracy required. Methods using site-specific data are preferred over other methods. These documents are non-binding guidance and not rules. EPA, the States, and others retain the discretion to employ or to require other approaches that meet the requirements of the applicable statutory or regulatory requirements in individual circumstances.

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CONTENTS

Section **Page**

1 Introduction 8.1-1

2 Source Category Description 8.2-1
2.1 Emission Sources 8.2-1

2.2 Factors Influencing Emissions 8.2-1

3 Overview of Available Methods 8.3-1

4 Preferred Method for Estimating Emissions 8.4-1

5 Alternate Methods for Estimating Emissions 8.5-1

6 Quality Assurance/Quality Control 8.6-1
6.1 Data Attribute Ranking System (DARS) Scores 8.6-2

7 References 8.7-1

TABLES, FIGURES

Page

8.2-1 Methane Emissions from Rice Cultivation 8.2-2

8.2-2. GHG Emissions from the Agricultural and Forest Sectors 8.2-3

8.4-1 Rice Field Flooding Season Lengths by State 8.4-2

8.6-1 DARS Scores: CH_4 Emissions from Flooded Rice Fields 8.6-3

1

INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating methane emissions from flooded rice fields. Companion chapters describe methods for estimating emissions of methane and other greenhouse gases (carbon dioxide, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride) from a variety of other sources.

Section 2 of this chapter contains a general description of the flooded rice field source category. Section 3 provides a listing of the steps involved in using the preferred method for estimating methane emissions from this source. Section 4 presents the preferred estimation method; Section 5 is a placeholder section for alternative estimation techniques that may be added in the future. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Most of the world's rice, and all of the rice in the U.S.,[1] is grown on flooded fields. When fields are flooded, aerobic decomposition of organic material gradually depletes the oxygen present in the soils and floodwater, and anaerobic conditions develop in the soils. At that point, methane is produced through anaerobic decomposition of soil organic matter by methanogenic bacteria. However, not all of the methane that is produced is released into the atmosphere. As much as 60 to 80 percent of the methane produced is oxidized by aerobic methanotrophic bacteria in the soils (Holzapfel-Pschorn et al., 1985; Sass et al., 1990). Some of the methane is also leached to ground water as dissolved methane. The remaining non-oxidized methane is transported from the soil to the atmosphere primarily by diffusive transport through the rice plants. Some methane also escapes from the soil via diffusion and bubbling through the floodwaters. Figure 8.2-1 graphically depicts the process of CH_4 production and its emissions.

Rice cultivation is a very small source of methane in the U.S. In 1996, methane emissions from this source are estimated to have been approximately 2.5 million metric tons of carbon equivalent (MMTCE) (U.S. EPA, 1998). This represents approximately 1 percent of total U.S. methane emissions from anthropogenic sources, and about 5 percent of U.S. methane emissions from agricultural sources.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 8.2-2 summarizes the agricultural and forestry activities associated with emissions of CO_2, CH_4, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

2.2 FACTORS INFLUENCING EMISSIONS

The water management system under which rice is grown is one of the most important factors affecting methane emissions. Upland rice fields are not flooded[2], and therefore are not believed to produce methane. In deepwater rice fields (*i.e.*, fields with flooding depths greater than approximately 3.3 feet), the lower stems and roots of the rice plants do not transport CH_4, thus blocking this primary pathway of CH_4 emissions. Therefore, while deepwater rice growing areas are believed to emit methane, the quantities released are likely to be significantly lower than in areas with more typical, shallow flooding depths. Also, some flooded fields are drained periodically during the growing season, either intentionally or accidentally. If water is drained

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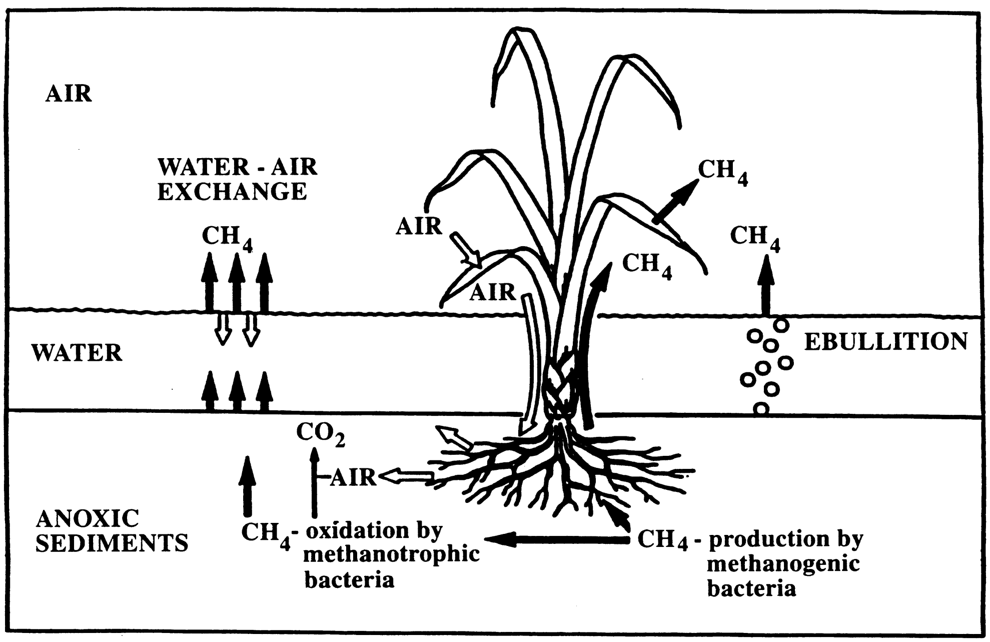
[1] Seven states grow rice: Arkansas, California, Florida, Louisiana, Mississippi, Missouri, and Texas.

[2] Note that all rice-growing areas in the U.S. are continually flooded; none are either upland or deepwater.

and soils are allowed to dry sufficiently, methane emissions decrease or stop entirely. This is due to soil aeration, which not only causes existing soil methane to oxidize but also inhibits further methane production in the soils.

Other factors that influence methane emissions from flooded rice fields include soil temperature, soil type, fertilization practices, rice cultivar selection, and other cultivation practices (*e.g.*, tillage, seeding, and weeding practices). Many studies have found, for example, that methane emissions increase as soil temperature increases. Several studies have indicated that some types of nitrogen fertilizer inhibit methane generation, while organic fertilizers enhance methane emissions. However, while it is generally acknowledged that these factors influence methane emissions, the extent of the influence of these factors individually or in combination has not been well quantified. Thus, the method for estimating emissions is based on a range of measured emissions per unit area of rice field flooding per day.

Figure 8.2-1 Methane Emissions from Rice Cultivation



Source: Schütz, et al. (1988)

Table 8.2-2. GHG Emissions from the Agricultural and Forest Sectors
A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✔	1	✔	13	✔	13
Animal Production: Enteric Fermentation			✔	6		
Animal Production: Manure Management						
Solid Storage			✔	7	✔	7
Drylot			✔	7	✔	7
Deep Pit Stacks			✔	7	✔	7
Litter			✔	7	✔	7
Liquids/Slurry			✔	7	✔	7
Anaerobic Lagoon			✔	7	✔	7
Pit Storage			✔	7	✔	7
Periodic land application of solids from above management practices					✔	Not included [a]
Pasture/Range (deposited on soil)			✔	7	✔	9
Paddock (deposited on soil)			✔	7	✔	9
Daily Spread (applied to soil)			✔	7	✔	9
Animal Production: Nitrogen Excretion (indirect emissions)					✔	9
Cropping Practices						
Rice Cultivation			✔	8		
Commercial Synthetic Fertilizer Application					✔	9
Commercial Organic Fertilizer Application					✔	9
Incorporation of Crop Residues into the Soil					✔	9
Production of Nitrogen-fixing Crops					✔	9
Liming of Soils	✔	9				
Cultivation of High Organic Content Soils (histosols)	✔	Not included [a]			✔	9
Cultivation of Mineral Soils	✔	Not included [a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✔	Not included [a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✔	10				
Abandonment of Managed Lands	✔	10				
Changes in Forests and Woody Biomass Stocks	✔	10				
Agricultural Residue Burning			✔	11	✔	11

[a] Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

3

OVERVIEW OF AVAILABLE METHODS

Methane emissions from rice cultivation can be estimated based on the acreage of rice grown (i.e., flooded) in a state,[3] estimates of the average number of days flooded, and emission factors for the amount of methane emitted per acre-day of flooding.

Note that ranges (low and high values) are used both for the average number of days that rice fields are flooded, and for the methane emissions per acre-day of rice flooding. To develop an estimated range of emissions, the low estimate will be based on the low values for both variables; the high estimate will be based on the high values for both variables.

The methodology described in this chapter is used in developing the U.S. Inventory of Greenhouse Gas Emissions (U.S. EPA 1998). As in the U.S. Inventory, this methodology uses the 1995 IPCC methodology (IPCC 1995). The 1997 IPCC methodology (IPCC 1997) is not used

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

[3] Wild rice is not included in these calculations because it is considered a grain, not a rice variety.

because it requires the use of seasonal emission factors which are not available for the U.S. Seasonal emission factors have not been developed for the U.S. because (1) season lengths are variable both within and among states, and (2) flux measurements have not been taken under all growing conditions in the U.S.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

To estimate methane emissions from flooded rice fields, the following steps are required: (1) obtain data on the area of rice fields flooded; (2) estimate the range in the number of acre-days of rice field flooding, and (3) develop the estimated range of emissions. These steps are outlined in detail below.

Step (1) Obtain Required Data

- *Required Data.* The information needed to calculate methane emissions from flooded rice fields is the total area harvested for the study year, and the length of the growing season (both low and high). Table 8.4-1 provides the range of average flooding season lengths by state.

- *Data Sources.* State agencies responsible for overseeing the agricultural sector should be consulted. Agricultural statisticians in each of the seven states in the U.S. that produce rice can be contacted to determine water management practices and flooding season lengths in each state. Alternatively, rice acreage for the major rice producing states can be found in the U.S. Department of Agriculture's annual *Crop Production* report (USDA 1998).

- *Units for Reporting Data.* Rice area flooded should be reported in acres, while the length of the growing season should be in days.

Step (2) Calculate the Number of Acre-Days of Rice Flooding

Within a state, different fields of rice may be flooded for different lengths of time. The number of acre-days flooded annually is equal to:

> (the number of acres within a certain cropping cycle length × the number of days in that cropping cycle) **+** (the number of acres with another cropping cycle length × the number of days in that cropping cycle) **+** [continue for all cropping cycle lengths].

The method presented in this chapter uses a simpler approach, based on low and high estimates of the average number of days that rice fields in a given state are flooded.

The climatic conditions of southwest Louisiana, Texas, and Florida allow for a second or "ratoon" rice crop in those areas. This second crop rice is produced from regrowth on the stubble after the first crop has been harvested. Emission estimates for these states should include this additional acre-days for the ratoon crop.

Rice fields for the second crop typically remain flooded for a shorter period of time than for the first crop. Recent studies indicate, however, that the methane emission rate of the second crop may be significantly higher than that of the first crop. The rice straw produced during the first harvest has been shown to dramatically increase methane emissions during the ratoon cropping season (Lindau & Bollich, 1993). It is not clear to what extent the shorter season length and higher emission rates offset each other. As scientific understanding improves, the emission estimates can be adjusted to better reflect these variables. At this juncture, it is recommended that the methane emission factors and flooding season lengths provided here for the primary rice crop be applied to the ratoon crop as well.

Table 8.4-1. Rice Field Flooding Season Lengths by State

State	Flooding Season Length (days)	
	Low	High
Arkansas	75	100
California	123	153
Florida[a] primary ratoon	90	120
Louisiana[a] primary ratoon	90	120
Mississippi	75	82
Missouri	80	100
Texas[a] primary ratoon	60	80

[a] These states have a second, or "ratoon," cropping cycle which may have a shorter flooding season than the one listed in the table. It is recommended that the user apply the same growing season length for both the ratoon and primary cropping cycles.

To calculate acre-days of rice flooding:

- Determine the area flooded for the study year. Those states that have a ratoon crop (Texas, Louisiana, and Florida) should include the area used for this crop in this calculation. Acreage for ratoon cropping has been estimated to account for about 30 percent of the primary crop in Louisiana, 40 percent in Texas (Lindau and Bollich, 1993) and 50 percent in Florida (Schueneman, 1995).

Example In 1996 in Louisiana the primary area harvested was 533,000 acres of rice. The area used for the ratoon crop in Louisiana is 30 percent of the primary area. Therefore, the total area flooded for the length of a growing season may be calculated as follows:

533,000 acres × .30 = 159,000 acres for the ratoon crop

159,000 acres for the ratoon crop + 533,000 acres for the primary crop = **692,000 acres** of rice flooded for the length of a growing season.

- Multiply the area flooded for the length of a growing season by the average number of days in a growing season (low and high estimates) to obtain the range in the number of acre-days that rice was flooded.

  Low Estimate: Area Flooded (acres) × Length of Growing Season (days, low estimate) = Acre-days (low estimate)

  High Estimate: Area Flooded (acres) × Length of Growing Season (days, high estimate) = Acre-days (high estimate)

Example The number of acre-days that rice was grown in California in 1996 is calculated as follows:

Area Flooded = 500,000 acres

Low

500,000 acres × 123 days = **61,500,000 acre-days**

High

500,000 acres × 153 days = **76,500,000 acre-days**

Step (3) Estimate Methane Emissions

The default methane emission factors were obtained from field studies performed in California (Cicerone et al., 1983); Texas (Sass et al., 1990, 1991a, 1991b, 1992); and Louisiana (Lindau et al., 1991; Lindau and Bollich, 1993). A range based on the minimum and maximum emission rates measured in these studies - 0.43 kg CH_4/acre/day to 2.28 kg CH_4/acre/day - can be applied to the areas and season lengths in each state.[4] Since these measurements were taken in rice

[4] Two measurements from these studies were excluded when determining the emission coefficient range. A low seasonal average flux of 0.24 kg/acre-day in Sass et al. (1990) was excluded because this site experienced a mid-season accidental drainage of floodwater, after which methane emissions declined substantially and did not recover for about two weeks. Also, the high seasonal average flux of 8.25 kg/acre-day in Lindau and Bollich (1993) was excluded since this emission rate is unusually high, compared to other flux measurements in the U.S., as well as in Europe and Asia (see IPCC, 1997).

growing areas of the U.S., they are representative of rice soil temperatures and water and fertilizer management practices typical of the U.S.

- For the low estimate, multiply the number of acre-days that rice was grown (low estimate) by the low estimate of the emission factor (0.43 kg CH_4/acre-day).

  Low Estimate: Number of Acre-Days (low) $\times$ 0.43 kg CH_4/acre-day
  = CH_4 Emissions (low) (kg CH_4)

- For the high estimate, multiply the number of acre-days that rice was grown (high estimate) by the high estimate of the emission factor (2.28 kg CH_4/acre-day).

  High Estimate: Number of Acre-Days (high) $\times$ 2.28 kg CH_4/acre-day
  = CH_4 Emissions (high) (kg CH_4)

- Divide the results by 1,000 to obtain methane emissions in metric tons. Then multiply by 12/44 (the ratio of the molecular weight of carbon to the molecular weight of CO_2) and by 21 (the global warming potential of methane) to obtain methane emissions in metric tons of carbon equivalent.

Example California's methane emissions from flooded rice fields in 1996 are calculated as follows:

(a)

	Avg. Acre-Days	Emissions Coefficient	CH_4 Emissions
low:	61,500,000 acre-days	$\times$ 0.43 kg CH_4/acre-day =	26,500,000 kg CH_4/yr
high:	76,500,000 acre-days	$\times$ 2.28 kg CH_4/acre-day =	174,600,000 kg CH_4/yr

(b)

low: 26,500,000 kg CH_4/yr $\div$ 1000 kg/metric ton $\times$ 12/44 $\times$ 21 = **152,000 MTCE CH_4**
high: 174,600,000 kg CH_4/yr $\div$ 1000 kg/metric ton $\times$ 12/44 $\times$ 21 = **1,000,000 MTCE CH_4**

5

ALTERNATE METHODS FOR ESTIMATING EMISSIONS

No alternate methods have yet been approved by the Greenhouse Gas Committee of the Emission Inventory Improvement Program.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emission estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

From field experiments it is apparent that methane emissions from rice fields are affected by many factors. The factors clearly identified by these field experiments are: (1) water levels throughout the growing season; (2) temperature; (3) fertilizer application; (4) soil type; (5) the cultivated variety (cultivar) of rice grown; and (6) agricultural practices such as direct seeding or transplanting. Data show that higher temperature, continuously flooded fields, some types of organic fertilizers, and certain cultivars lead to higher emissions. At present, however, there are insufficient data to incorporate most of these factors. Nonetheless, estimates can be improved substantially by incorporating the current knowledge on the first two factors, namely water levels and temperature. For some states, the effects of organic and mineral fertilizers could be included.

Application of the commercial nitrogen fertilizers ammonium sulfate or urea has generally been found to reduce CH_4 emissions, especially if the fertilizer is deeply incorporated into the soil. This is believed to be due to suppression of CH_4 production as a result of the addition of sulfate or ammonium ions. Application of organic fertilizers (*e.g.*, rice straw, composted rice straw, animal wastes), whether or not in combination with mineral fertilizers, has been found to enhance CH_4 emissions in most cases. The organic fertilizers provide an additional carbon source for the production of CH_4 in the soil.

Water management also influences CH_4 emissions since it is only through continuous flooding that paddy soil remains sufficiently anoxic for methane production to occur. Cultivar selection is likely to affect CH_4 emissions through two mechanisms: (1) root exudation and (2) gas transport. Many studies have observed two or three maxima in CH_4emissions during the growing season with the last one or two peaks occurring during the reproductive stage of the rice plants. These latter emission peak(s) may be due to peaks in CH_4 production that result from the plants providing soil organic bacteria with organic root exudates or root litter at this time (Schütz et al., 1989). The degree of root exudation that occurs is believed to vary between cultivar types. The rice plant also affects CH_4 emissions through gas transport mechanisms. Downward oxygen transport through the plant (and subsequent oxidation of CH_4 in the rhizosphere) and upward methane transport probably varies between cultivars. Gas transport mechanisms may also play a role in controlling the latter emission peaks, *e.g.*, methane transport may be more efficient during the reproductive stage of rice plants than at other developmental stages (Sass et al., 1990).

States are encouraged to go beyond the basic method provided here and add as much detail as scientifically justified, based on laboratory and field experiments on how the above factors may influence emissions. For example, states may wish to develop their own emission coefficients, especially if wetland rice is a major crop.[5] Also, where data are available on fertilizer type used, states may wish to incorporate this information into their calculations.[6] If additional detail is included, then state emission inventories should be fully documented, indicating sources for all values used in the calculations.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (e.g., the acre/days of rice field flooding), and the other four are related to the emission factor (e.g., the amount of methane emitted per acre/day of rice field flooding). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of one to ten, where ten represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes and divided by ten; the results are then averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the US government sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data.

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[5] As discussed above, because of the large variability in methane emissions over the growing season, states should use seasonally-averaged daily emission coefficients (*i.e.*, the seasonal average of average daily emission coefficients based on semi-continuous measurements taken over an entire growing season). See Braatz and Hogan (1991) for a description of appropriate emission measurement techniques.

[6] See IPCC (1997) for information on how to incorporate such data into the calculations.

TABLE 8.6-1

DARS SCORES: CH_4 EMISSIONS FROM FLOODED RICE FIELDS

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	2	The emission factor is based on reported values for field measurements of methane emissions from rice fields. The measurements varied widely.	7	The number of acre-days of rice cultivation is estimated based on harvested acreage and low and high estimates of the length of the growing season. The DARS formula does not apply to this scenario.	0.14
Source Specificity	10	The emission factor was developed specifically for flooded rice fields.	5	The activity measured, acre-days of rice cultivation, is somewhat correlated to the emissions activity.	0.50
Spatial Congruity	5	The emission factor was developed for the U.S. as a whole. Field measurements varied between states by as much as two orders of magnitude.	10	States use state-level activity data to estimate state-wide emissions.	0.50
Temporal Congruity	7	The emission factor is based on daily average emissions, presumably over a portion of the growing season. Daily emissions are assumed to vary moderately over the course of a growing season.	10	States use annual activity data to estimate annual emissions.	0.70
				Composite Score	**0.46**

7

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